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Overcoming the lock-out of renewable energy technologies in Spain: The cases of wind and solar electricity

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Abstract

This paper applies an evolutionary economics framework to analyse the factors leading to lock-out of renewable energy technologies (RETs). The cases of wind and solar photovoltaics (PV) in Spain are empirically analysed. The paper shows that a wide array of interrrelated factors (technoeconomic characteristics of technology components, system-level infrastructure and institutional factors) can create both *barriers* to the wide diffusion of RETs and can also be *drivers* that foster an escape from a lock-in situation. Based on this analysis, the paper suggests several policy measures which may help to overcome the lock-out of promising renewable energy technologies.

Keywords: Evolutionary economics; Solar PV; Wind energy; Lock-in; Lock-out; Renewable energy technologies; Technology policy

Contents

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1. Introduction

Wind power and solar photovoltaics (PV) are promising, and in some cases proven, energy technologies that offer attractive environmental performance characteristics. However, despite their apparent benefits, the diffusion of wind and PV technologies has been uneven on both national and international scales. This article explores this uneven diffusion through two detailed case studies of the Spanish wind electricity and solar PV sectors. Interestingly, Spain is a leader in the deployment of wind energy, but lags significantly in the diffusion of PV compared with other countries. Proximate causes, like differential costs of the two technologies or available resources, provide only limited explanatory power. For example, Spain has both excellent wind and solar resources, thus favouring the adoption of both technologies. But, while Spain is currently a world leader in wind energy deployment (only behind Germany and on par with the US) the adoption of solar energy is minimal despite the country's comparatively natural resource advantage with its high rates of insolation. The lag is especially interesting when compared with countries like Germany that receive much lower solar radiation, but are world leaders in PV deployment.

This paper evaluates these differential diffusion rates from the perspective of evolutionary economics to better understand the causal factors behind the deployment of renewable energy technologies (RETs) in the Spanish context. It shows that economic and institutional factors play decisive roles in fostering or inhibiting diffusion. The paper first elaborates a theoretical framework that builds from an evolutionary economic perspective and takes into account market, technological and institutional factors which influence diffusion. The framework is then applied to the two case studies, wind and PV, set within the context of the Spanish energy sector to explore the causal factors for the differential diffusion rates of wind and PV technologies. Finally, the paper draws conclusions that can inform policy making and minimise the potential lock-out of promising energy technologies.

2. The techno-institutional framework

New technologies, like wind energy and PV, do not enter into a virgin market terrain, but instead must compete with pre-existing technologies that currently provide similar services. This means that "history matters" and that new technologies often have to adapt

in path-dependent ways to previous investment and policy decisions, made often decades in the past. Pre-existing infrastructure, both physical and institutional, can create important constraints on the adoption patterns of new technologies. Failing to account for the path-dependent nature of technological evolution can limit the potential success of new technological offerings.

In the case of new energy technologies, they must compete with large, well-established systems which, in some cases, are the biggest structures ever created by humankind. Energy systems can be characterised as Techno-Institutional Complexes (TIC) which include the large physical technologies themselves and the social organisations and institutions that build and manage them [1]. TIC emerge through a path-dependent process driven by increasing returns to scale, which powers their growth and ultimately fosters numerous sources of quasi-irreversibility or lock-in. Fig. 1 illustrates graphically the elements of the TIC Framework. It has been argued that these systems are largely responsible for the lock-out of promising energy technologies [1–3].

The focus of the framework is at the level of complex technological systems like electricity generation, telecommunications and transportation, that rely on network relationships among complimentary technologies, organisations and governing institutions. They emerge through a path-dependent co-evolutionary process that begins when innovation creates several technological variants that compete in an environment of technological increasing returns to scale [4]. Ultimately one variant emerges from the competition as a dominant design, locking-in key technological architectures [5]. Surviving dominant design-producing firms organisationally lock-in around standardised decision routines, core competencies, distribution networks and customer–supplier relationships, which conditions their investments in non-dominant design technologies [6]. As the system scale expands, complementary industry and interindustry networks, including financial

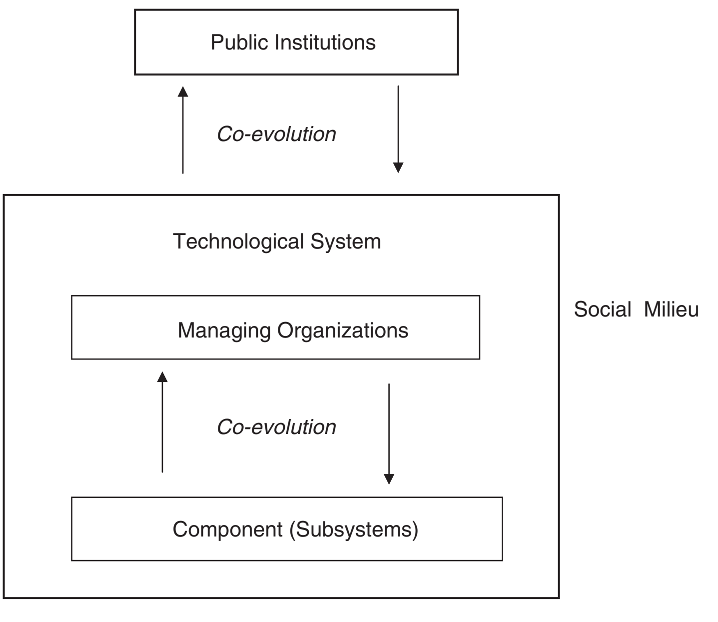

Fig. 1. The elements of a techno-institutional complex.

Table 1
Elements of a techno-institutional complex

Type of lock-in	Source
Technological	Dominant design, standard technological architectures
Organizational	Routines, hierarchies, customer–supplier relations
Industrial/System	Industry standards, technological interrelatedness, value chain relations
Societal	System socialization, adaptation of preferences and expectations
Institutional	Government policy intervention, legal frameworks, departments/ministries

institutions, emerge and lock-in coordination standards, relationships and capital investment patterns. If the system becomes socially pervasive, advocacy groups, voluntary associations and the media socialise the system, adapting preferences and expectations to continued system dominance. Finally, government may intervene in system growth for policy reasons (national security, universal service, anti-trust/natural monopoly, etc.) and encourage system expansion through subsidies, incentives or outright ownership. The intervention by government, which overrides market forces, signals the emergence of a techno-institutional complex. Table 1 broadly summarises the ‘‘types’’ of lock-in discussed.

The establishment of a TIC facilitates the extension of useful technological systems by ensuring lower economic, social and psychic costs of the dominant design relative to alternative technologies. Thus thinking in terms of the techno-institutional framework can help structure public and private efforts to extend new technological systems, like renewable energy technologies. However, while the TIC can create stability, predictability and possibly reliability in the system, it can also create inertia to change which can prove problematic over time. As public policy and private investment decisions are frequently made with limited foresight and discounting of potential future risks, unintended consequences can become locked in along with the TIC. This appears to be the case with environmental disutilities created by fossil fuel-based energy systems, which were not foreseen when the systems were initially built.

Despite the barriers that engender lock-out of desirable technologies, technological and institutional change have occurred repeatedly in history. Sources of energy and systems to convert it have varied dramatically through history and include agricultural collection of solar energy and conversion through animal and slave labour thousands of years ago, to the use of whale and animal oils hundreds of years ago, to the modern reliance on fossil fuels today. A new change will certainly occur again in the future, especially if the predictions of climate disruption and other induced environmental change are borne out. The fundamental question is ‘‘will promising renewable energy technologies overcome the lock-in of fossil fuel systems before irreversible environmental damage occurs?’’ and, if not, ‘‘can policy efforts facilitate a transition to a new energy infrastructure?’’

We pursue these questions by undertaking an empirical case study which applies the TIC framework to the case of the Spanish energy sector. We evaluate each of the elements of the TIC—technological, organisational, industrial systems, institutional and social—where they are applicable to the two technologies under consideration, wind and PV. Each of the TIC elements can play a role in facilitating or constraining the adoption of new technologies. The way interconnection (system) standards are designed, for example, can either lock-out alternatives from the grid or facilitate their inclusion. Government policy

can either reinforce (lock-in) the dominant technology, or it can foster variety and alternatives. We address these dual roles in the case analyses that follow by organising the factors based on whether the create *barriers* to the adoption of RET or whether they are *drivers* of RET diffusion.

3. Empirical studies on renewable energy technologies in Spain

In this section an evolutionary economics interpretation of the barriers (and drivers) for the diffusion of two key RETs (wind and solar PV) in Spain is provided. Data for these two in-depth case studies have been obtained from a variety of sources and include official statistics, reports by industry associations, manufacturers, energy suppliers, investors and NGOs. A small number of unstructured interviews with key actors and experts in the wind and solar realms have been carried out. The material collected has been interpreted in the light of the theoretical framework set in Section 2. These two technologies have been chosen for this study because Spain is well endowed with both wind and solar energy resources (see below) compared to other EU countries, thus effectively controlling for the effect of resource endowment.

3.1. On-shore wind

The diffusion of wind on-shore power in Spain over the period 1995–2004 can be described as impressive and has made Spain second in wind energy installed capacity, only behind Germany and on par with the US.

Wind power adoption statistics are presented in Table 2, but aggregate data obscure important regional differences. Five regions account for 85% of the total installed capacity in Spain. The province of Galicia leads the way, followed by Castilla-La Mancha, Castilla y León and Aragón. In contrast, there is no deployment in the capital region of Madrid, Cantabria and Extremadura regions.

3.1.1. Barriers and drivers

The Spanish wind energy model has certain peculiarities compared to other Northern European countries. Large and medium size on-shore wind farms predominate in Spain,

Table 2
Accumulated wind power in Spain (1995–2003)

Year	Power installed (MW)	Accumulated power (MW)
1995	46	119
1996	95	214
1997	213	427
1998	407	834
1999	705	1539
2000	795	2334
2001	861	3195
2002	1440	4830
2003	1377	6207
2004	1746	7953

Source: [7] and APPA.

whereas other countries follow a more decentralised model, with smaller clusters and even individual wind turbines scattered over the territory. Wind energy investors in Spain are mostly consortia of power utilities, regional government and turbine manufacturers [8], with the role of private individuals insignificant compared to other countries.

3.1.1.1. Drivers of wind energy diffusion. Ten years ago, the installed wind capacity in Spain was similar to many other countries, but deployment has increased markedly over the period of data. What are the reasons behind the accelerated adoption of wind energy in Spain? Diffusion cannot be attributed to any single factor but, rather, several interrelated factors are involved:

Resources: Spain benefits from high-quality wind potential. According to the European wind resource map [9], more than 80% of the Spanish territory has good wind resources (speed above 7 m/s, and power above 400 W/m^2), and several places in the south, north-west and north-east have excellent wind resources (speed above 9 m/s and power above 850 W/m^2) [10]. Thus, lack of resource is not a constraint for the deployment of wind power (see below).

Costs and technical factors: Learning effects, economies of scale and R&D efforts have substantially reduced wind energy costs [12] and system components. According to [11], costs in Europe have fallen by 20% over the last 5 years. In Spain, data shows that these costs have gone down from 1700 €/kW in 1986 to 864 €/kW in 1999 [13] and they are expected to reach 700 €/kW in 2010 [14]. The average size of installed wind turbines has risen every year, reaching 808 kW in 2002 [7]. Mass production and technological improvements have reduced the costs of construction/installation and operation/maintenance, leading to improved returns on investment [15].

The level of technological competency in Spain is high relative to international standards. Spanish wind turbine manufacturers have a position of international leadership, being among the world's 10 largest manufacturers commanding a joint market share of 16.4% in 2002.

Factors driving cost reductions are interrelated, making it difficult to separate the effect of individual drivers. The reduction in manufacturing costs is partly a result of support policies in several countries, leading to an increase in the market size and to cost reductions. It is not surprising that the three countries which have experienced the largest increase in wind energy deployment in Europe (Germany, Spain and Denmark) are also those with the top turbines manufacturing firms [16].

Highly supportive institutional framework: high support levels, stability and certainty of promotion schemes: Institutional factors, including national promotion schemes, have been crucial factors behind the widespread diffusion of wind energy in Spain. The main pieces of legislation impacting wind energy include the Law of the Electricity Sector (*Law 54/97*), the 2818/1998 Royal Decree on the Special Regime, the 1999 Plan for the Promotion of Renewable Energy (PFER), the Plan of Electrical and Gas Infrastructures (2002). A modification of the existing system was made in 2004 (Royal Decree 436/2004) [17]. These regulations have provided a strong incentive through generous high feed-in tariffs awarded per kWh generated. Price support measures (feed-in tariffs) give two alternatives to renewable generators, either they receive a premium (on top of the market price) or a fixed price. Both have been adjusted annually since 1999 by the Government and the support is paid by the final consumer in its electricity bill. Table 3 illustrates the evolution of the premiums and the fixed prices for wind since 1999.

Table 3
Trends in wind electricity premiums and fixed prices (in €cents/kWh)

WIND	1999	2000	2001	2002	2003	% variation (1999–2003)
Premiums	3.16	2.87	2.87	2.89	2.66	−18.2%
Fixed prices	6.62	6.26	6.26	6.28	6.21	−6.2%

Source: [22].

In addition to the supports, the government has also used targets to stimulate adoption. A target of 13,000 MW of installed capacity by the year 2011 has been set for wind energy. This will be crucial to help Spain achieve its RES-E Directive target (Directive 77/2001/EC): that 29.4% of electricity consumption in 2010 comes from RES. The stability and certainty of the Government's promotion framework, and the resolute role in the promotion of wind energy taken, has its roots in its perceived environmental and socioeconomic benefits, especially job creation.

There has been a reduction of the prices paid. This is criticised by the Spanish Renewable Energy Association (APPA), which claims that this will not help achieve the ambitious targets set for wind energy (see below). Public officials argue that the consumer is loaded with the high costs of public promotion of RES-E and defend the reduction on the basis of the "sharp reduction in wind costs" [18].

One of the main advantages of this system is its relative simplicity, lack of bureaucracy and stability but the sector asks for a long-term price guarantee like in Germany and more certainty of the support that will be provided during the payback period. They criticise the annual revision of support prices (dependent on the evolution of the average power market price) and claim that knowing ex ante the support to be granted would allow them to reduce the capital costs and to ensure the availability of financial funds. This shows that an accurate regulatory framework is crucial for the widespread diffusion of RETs.

Local acceptance and NGOs: The larger social context has been supportive of wind energy and is generally regarded by local actors as highly beneficial for its associated employment and development opportunities. Environmental NGOs have been generally supportive, although the local NGOs have sometimes criticised wind for the visual intrusion that turbines may cause. While not a major concern today, experiences in other countries like the UK indicate local community concerns could be an important obstacle in the future.

The role of pioneers: The role of a handful of "visionarie" entrepreneurs has been important in the development and initial adoption of wind electricity in Spain. These small entrepreneurs and engineers saw the business potential of wind energy and undertook the initial risky investments. They showed that investing in wind electricity was technically and economically feasible, which paved the way for further investments.

Financial institutions: Finally, financial institutions have been supportive of wind energy, given the proven profitability of wind energy investments, which is partly related to other factors (stability of support schemes, high level of support and continuous costs reductions). The regulatory stability, discussed above, and the demonstration of successful installations has decreased perceived investment risks and led to favourable lending conditions [8]. Here again different factors have mutual reinforcing effects, in that low

lending rates contributed to greater profitability and stimulate more interest in wind investments.

3.1.1.2. Barriers to wind energy. While for the most part the above drivers have dominated, barriers to diffusion do exist. Reaching the wind energy target for 2011 will depend on the removal of a number of potential barriers.

Authorisation procedures: Institutional arrangements create barriers including authorisation procedures for construction, connection to the grid and initiating production in wind farms. These regulations often delay the granting of permits, increasing lead times [19] transaction costs and risks for project developers. In Spain, this is a very relevant problem with its three levels of government competency: national, regional and municipal.

Several administrative levels: Authorisation procedures involve many administrative jurisdictions (municipal, regional and national). There is an overlapping of procedures and competencies between the national and the regional governments. Unlike in other MS (i.e., Germany), there is no catch-all application process by virtue of which all administrative procedures are reviewed and one single permit is issued [21]. Several application proceedings must be conducted contemporaneously and are interlocking at specific stages.

The implementation of wind farms is affected by 60 different regulations involving 40 different procedures between different administrative levels [22] and causing lead times of 4 to 8 years [20,23]. A streamlining of these procedures is desirable.

Distinct administrative procedures per region: Competency for authorisation of new wind capacities is at the level of regions (Autonomous Communities, AACC). However, different procedures for the authorisation of wind farms exist in different AACC without harmonisation at the state level. Investors are thus forced to consult the different legal and authorisation procedures in each region where they plan to install a wind farm, raising the costs of multi-location investment. In addition, within each region, there is a lack of objective and quantitative criteria to assess the environmental impact of wind installations. This leads to long delays in the reply of AACC to the environmental impact assessment submitted by project developers [24] creating additional costs for wind investors.

Municipal Authorisation: Municipalities actively participate in the authorisation procedure and they can delay the actual implementation of a wind energy farm. The complaint of local residents and NGOs could block the permitting of wind energy projects for substantial periods. Information campaigns, environmental impact assessments and agreements between the project developer and the local communities may reduce the opposition of local communities [25]. Finally, project developers have to pay regulated charges to the local administration for the use of the public domain. However, effective payments usually exceed those regulated charges [13] causing uncertainty on the final cost for the investor.

Difficulties in accessing the grid and the costs of interconnections: The larger existing technological infrastructure and institutional frameworks create important barriers. Even though article 26 of the Law 54/1997 gives wind energy generators the right to feed power into existing power lines, actually gaining access to the grid is the major obstacle:

Limitations and weakness of the grid infrastructures: Wind farms are usually located in low-density rural areas where grid infrastructure is often weak. Investments to improve or extend the existing electricity infrastructure are required, but the costs fall on project developers, who must make large investments in the connection line.

Costs of deviations and tension hollows: The Spanish system penalises individual generators for deviations from scheduled production (approximately at 5 €/MWh), a cost paid to distributors. Wind energy is penalised compared to more predictable conventional electricity because wind energy deviations are treated in the same manner as conventional electricity.

Grid access procedures: There is a certain conflict in the Spanish regulation between favouring the access of renewables to the grid and protecting grid security. On the one hand Spanish legislation guarantees obligatory and free grid access to renewables and requires the grid operator, Red Eléctrica de España (REE), to take all wind generation onto its grid. On the other hand, in 2001, REE calculated in 13,000 MW as the amount of wind electricity it was prepared to handle by 2011 and the basis of grid security and reliability. However, wind generators defend a total installable power of 40,000 MW as a limit which is supported by grid integration studies in other countries [26].

There are improved methods for predicting output from wind power installations. But wind forecasting is also an issue of debate between the wind industry and REE. The latter is demanding better forecasting while the former ask for increases in production subsidies if generators have to pay the costs of forecasting.

To sum up, the lack of infrastructures along with systemic and institutional difficulties of grid connection has led to uncertainties and additional costs, delaying the installation of wind farms. Going forward there is concern that costs may increase, due to the price of more complex wind turbines and the rising costs of grid connection and of administrative procedures [24,27]: Furthermore, although significant high-quality wind resources still exist in Spain, the best places have already been taken, possibly driving up costs in the future.

3.2. Solar

Even though they started with similar initial conditions, solar PV electricity is a very different case from wind. PV has not yet taken off in Spain despite the excellent solar resources of the country. For PV, the PFER (National Renewable Energy Promotion Plan) includes a target of a total installed capacity of 144 MWp (115 grid-connected) in 2010. By the end of 2003, only 28 MWp had been installed (Table 4).

Table 4
Cumulative installed PV power as of the end of 2003

Country	Cumulative off-grid PV capacity (kW)	Cumulative grid-connected PV capacity (kW)	Total installed PV power (kW)	Total installed per capita (W/capita)	Power installed 2003 (kW)	Grid-connected power installed in 2003 (kW)
Spain	18,820	9180	28,000	0.68	8000	6500
Germany	19,700	390,600	410,300	4.97	133,000	130,000
Japan	78,893	780,730	859,623	6.74	222,781	216,535
USA	161,600	942,330	275,200	0.94	63,000	38,000
Estimated total	407,316	1,401,648	1,808,964		475,887	428,486

Source: Downloaded from IEA-PVPS (http://www.iea-pvps.org).

Table 5
Cumulative installed PV power (kW)

Country	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	1994–2003 (%)
Spain	5.7	6.5	6.9	7.1	8.0	9.1	11.6	16.0	20.2	28.0	19.3%
Germany	12.4	17.8	27.9	41.9	53.9	69.5	113.8	194.7	277.3	410.3	47.5%
Japan	31.2	43.4	59.6	91.3	133.4	208.6	330.2	452.8	636.8	859.6	44.5%
USA	57.8	66.8	76.5	88.2	100.1	117.3	138.8	167.8	212.2	275.2	18.9%
Estimated total	164	199	245	314	396	520	728	990	1333	1809	30.5%

Source: Downloaded from IEA-PVPS (http://www.iea-pvps.org).

When put in an international comparative perspective (Table 5), Spain is still far behind the world leaders in PV installation, some of which have much lower solar radiation. For example, there are 10 times more PV panels installed in Germany than in Spain, indicating that insolation is not the only explanatory factor [28]. The rest of countries have also experienced significant growth rates. The deployment of solar PV differs per region and four regions (Navarra, Madrid, Castilla-La Mancha and Cataluña) concentrate 80% of total installed capacity.

3.2.1. Barriers and drivers

Solar PV can be installed as stand-alone or grid connected systems with multiple applications within these two categories. Although some drivers and barriers are common to all types of applications, others are category specific. In this paper we focus on grid connected applications (integration in buildings and PV electricity production plants) [29].

3.2.1.1. Barriers to PV energy. *High initial costs*: Although technological component costs are constantly declining, PV investments are still expensive relative to alternatives, which discourages its deployment. High cost limit diffusion and create a negative reinforcing effect by not allowing the scale economies that are needed to generate cost declines that could make PV competitive with conventional electricity. The result is a vicious circle where the technology is not adopted because it is expensive, and it is expensive because it is not adopted. This is compounded by system factors that make it costly to retrofit PV systems into buildings which are not PV ready. Switching costs in these cases are much higher than if the buildings were prepared from the beginning to integrate PV.

Lack of an accurate legal framework and insufficient support: The institutional framework for renewables discussed in the previous wind section also applies to PV. However, in addition to the basic feed-in tariff there are other relevant instruments supporting PV deployment:

The Royal Decree 2818/1998 set an incentive of 39,668 €cents/kWh for PV installations connected to the grid with a capacity lower than 5 kW and 21,634 €cents/kWh for installations above 5 kW (this included the price of the electricity sold to the grid, 3.6 €cents/kWh). This feed-in tariff is significantly lower than in most other European countries (see [11]). Those with a capacity above 100 MW are ineligible for funding generating an extended payback period of 13 to more than 25 years [30].

The National Government provides investment subsidies and soft loans, while regional authority subsidies can cover between 15% and 50% of total investment [31]. However, PV generators claim that subsidies are not always granted or that the granting is arbitrary and varies by region. The total subsidies budgets are limited and given on a "first-come–first-serve" basis, creating institutional uncertainty for investors.

Administrative barriers: Administrative procedures to install the PV modules and receive support (subsidies and feed-in tariff) are often complex, cumbersome causing costly delays and long lead times [32].

Financial barriers: Funding conditions are not as favourable compared to wind and generate disincentives. The above factors create higher investment risks and longer payback periods.

Companies in the conventional electricity sector: The Spanish solar PV association (ASIF) claims that conventional utilities regard PV as a threat and create barriers by exploiting their dominant position in the system. The opposition of existing firms to new technologies is a common in the history of technological change [1].

Training and skills of equipment installers: Failed installation has a negative demonstration effect and discourages the adoption by others. This makes experienced installers and suppliers very relevant actors in the change of technological regimes. Installation needs to be carried out by well-trained specialised suppliers. Only if the installation is carried out properly will solar systems work properly and expectations on its performance will be met. The Royal Decree 1663/2000 requires that PV installers have certain qualifications and specifies the knowledge skills required to carry out these installations. However, ASIF claims that this Royal Decree, which has entered into force, is not applied in practice.

Lack of information: Technological diffusion research demonstrates that dissemination of information is a crucial factor in the widespread adoption of a technology. According to ASIF, grid-connected PV suffers from lack of information in several issues (feasibility and costs of the technology and existing subsidies, difficulties and regulatory vagueness regarding grid connection and rights of solar PV generators), which dissuades potential adopters who are initially in favour of installing PV.

Connection to the grid: According to PV generators, before 2000 there were no grid connection regulations, which allowed utilities to set exorbitant charges [33]. The Royal Decree 1663/2000 set technical conditions for connection of PV systems to the low-voltage grid. However, barriers remain. Most PV generators have a medium voltage grid connection and are obliged to install a transformer, substantially raising the cost of the PV installation. Investments in grid reinforcement further discourage PV projects. Generators claim that grid access continues to be discriminatory and at unfair fees and directly accuse the grid operator and utilities of preventing PV access. Again, this is a problem of intersystem competition with interests using market power to block the introduction of a new technology.

Integration in buildings: Grid-connected installations are mostly integrated into building roofs or facades. Spain has undergone a housing and construction boom in the last years, which is expected to continue in the near future. Half a million new buildings have been constructed every year without including conditions for future PV installation. This has created an installed base of buildings that are not PV ready. By not preparing the buildings for future PV installations, they have made PV installation less attractive, because of the retrofit cost discussed above.

3.3. Drivers for PV energy

While barriers appear dominant at this time, there are existing drivers of PV energy in Spain.

Resources: Spain has the best solar resources in Europe, particularly in the south and east regions. Average radiation, according to [30], is 1600 kWh/year/m^2.

Costs reductions: The costs of "ready to install" PV modules have been falling by 5% in the last decades (a 75% accumulated reduction in the last 20 years) and most studies estimate large potential for costs reductions in the next 20 years [34]. According to [11], the learning rate of PV systems is expected to be around 20%, although for other sources [35] they could be as high as 40% for grid-connected installations. The costs per kilowatt-hour of PV in Southern Europe are projected to fall from 23 €cents/kWh in 2001 to around 7 €cents/kWh in 2020. These lower costs should enhance adoption.

Rural and regional development opportunities, reduction of unemployment levels and local acceptance: Spain is still one of the OECD countries with the highest unemployment rates, especially in rural areas. The installation of PV electricity production plants in these areas is seen by the government as a development opportunity. Currently 4000 jobs are linked to the PV sector in Spain (2500 are direct) and the socioeconomic benefits of PV make it attractive for local communities, where acceptance is crucial for PV penetration.

Institutional factors: Several factors could lead to an institutional push for PV in the future. Compliance with the Kyoto Protocol makes the increased deployment of RES-E attractive. Spain, where the energy sector accounts for three-fourth of GHG emissions, is one of the European countries farthest away from Kyoto compliance. PV and wind are strategic sectors contributing to the minimisation of the country's deviation from its Kyoto target. Kyoto mechanisms like targets and the Clean Development Mechanism may increase the size of the PV market worldwide, fostering the export of Spanish technology to new markets. PV has also been discussed as a way to reduce the energy dependence on foreign fossil fuels energy sources of the Spanish economy.

The socioeconomic and environmental benefits of PV, coupled with the high levels of solar radiation, have fostered an institutional push both at the national, regional and municipal levels in Spain. Many large cities in Spain have approved regulations requiring the obligatory installation of solar PV on new buildings and some regional energy plans prioritise the use of PV. As discussed, the Royal Decree 436/2004 substantially improves the treatment of PV at the national level. Such measures are justified by the fact that PV is much more cost-effective if installed during construction, where the impact on the total building costs is low [11]. A recent law (the Building Technical Code) will require in 2006 that new and rehabilitated buildings install PV panels for water heating purposes.

Future technological improvements and costs reductions will reduce the financial burden of publicly promoting PV. ASIF estimates that, to reach 2125 GWp in 2030, the total support provided by the Spanish authorities should be around 1250 M€ (around 0.23% of the total electricity bill in Spain and less than 1'€/year/family) [36].

Spanish PV industry and science and technology PV system: The Spanish PV cell and PV installation industry is highly competitive and recognised for its quality, flexibility, innovativeness and commercial dynamism. It is the leading European manufacturer, exporting 85% of its production, representing 40% of European and 7% of world production. It is currently growing at a rate of 30% annually and lags only behind the USA and Japan. The Spanish firm Isofotón is the top European cell producer and

two other firms (BP Solar and Astra Solar) are among the top 8 largest producers and are linked through 25 R&D PV centres.

Certain inherent technoeconomic characteristics of the technology itself may favour its market penetration in the future: PV reduces transmission losses (compared to more centralised alternatives), it is versatile, modular, user-friendly, fast and easy to install and operate, it does not need large infrastructures, it has a long duration (the useful life of PV modules is more than 30 years), minimum maintenance, low O&M costs (including low fuel costs), it can be integrated into existing buildings, its implementation does not cause environmental pollution and PV electricity is generated where it is consumed, thereby reducing grid saturation.

The new Royal Decree (436/2004) may provide an additional stimulus to PV because it increases the incentive to 41 €cents/kWh for plants smaller than 100 kW and 21 €/cents for larger plants. The feed-in tariff also introduces a guarantee of 25 years from the date of commissioning. This stability follows the highly successful German model.

4. Discussion and policy recommendations

Evolutionary Economics shows that radical changes, like the shift from fossil to renewable energy, are not frequent and often face many different barriers. Notwithstanding, there might be windows of opportunity which may facilitate the introduction of radical technological changes. The systemic and dynamic features of an Evolutionary Economics approach can provide insight on the factors generating technological lock-out in RETs and to suggest policy strategies to overcome this condition.

It has to be acknowledged that the electricity sector has become locked into centralised, large thermal-based systems that have undergone increasing returns improvements in the human, financial and institutional resources, which creates intense inertia. New technology may not be compatible with the characteristics of the existing system, and are often handicapped in competition. Furthermore, new technologies represent a threat for the established technology and the firms that have invested in it. In contrast, RETs have not undergone equivalent growth that will improve the technology and reduce their costs and is assessed with the criteria used to evaluate the old technology. This can fail to take into account the benefits of the new systems. Complementary technologies such as transformers have to be adopted in order for the new technologies to integrate with the existing technology. All of these create challenges for policy makers interested in supporting promising new technologies.

However, windows of opportunity arise in the evolution of technologies that can favour the exit from lock-in. As preferences change over time, existing technology might not be able to meet the new social and market demands (i.e., environmental protection). Likewise, some negative features of the old technologies and which were relatively hidden can manifest and some positive features of the new technology can be given value. These provide openings for the new technology.

This paper has applied an evolutionary economics framework to identify and analyse the factors which are impacting the diffusion of solar PV and wind in Spain. The technologies show some similarities, being intermittent, capital intensive but with low O&M costs. They differ, however, in other respects that is demonstrated in their differential diffusion rates. The case study on wind energy in Spain shows that several factors acting together, simultaneously and in an interrelated way, allowed a widespread diffusion of the

technology. These include excellent wind resources, substantial cost reductions, a high technological level of the domestic wind industry, a highly supportive and stable institutional framework providing certainty for investors and reasonable profit margins, a society attaching high value to the benefits of wind energy and the role of several pioneers whose investments showed the feasibility and reliability of wind energy deployment. As a result of all those factors, financial institutions have been able to provide loans for investments at relatively low interest rates (low risk premium).

However, some factors may stand in the way of future wind energy growth rates. These include long lead times due to cumbersome authorisation procedures, difficulties in accessing the grid and costs of connection, higher cost of wind turbines and increasing scarcity of high-wind locations. These factors are related to a technology which has reached a critical mass and which is really competing with the conventional technology, being considered as a real threat by those with interests in the later.

As shown, PV is very different case. PV factors of importance are sometimes the opposite of wind energy. They include high initial costs, low support levels and non-guaranteed support (feed-in tariffs), administrative and financial barriers, lack of professionality of some equipment installers creating a negative demonstration effect, lack of interest by conventional companies, lack of information and problems in accessing the grid and building integration. Drivers for an increased penetration of PV in the future include the high solar radiation in Spain, expected cost reductions, its socioeconomic and environmental benefits, recent public policy measures and a relatively strong domestic industry and science and technology PV system.

4.1. *Policy recommendations*

The analysis of specific barriers and drivers should be the basis to propose public policy measures that seek to foster the diffusion of RET. Several instruments currently exist to promote renewable energy technologies in the electricity sector (tradable green certificates, feed-in tariffs, etc.) and are relevant elements in a policy mix. However, by themselves, they are unlikely to change the technological regime because they fail to address structural barriers that are unrelated to financial support (for example, the issue of grid connection). Thus a mix of instruments appears necessary, targeted at different facets of the lock-in problem, which impact the supply and demand for technology and also the larger context in which it will be embedded (see Fig. 1).

4.1.1. *Solar PV*

In the case of Spain, some of the lessons from the wind energy case can be used to suggest policy measures which may help to foster solar PV diffusion. PV's high costs is still the major barrier and cost reduction should be a priority. Cost reductions create a self-reinforcing effect by expanding the effective market and fostering scale and learning effects. These encourage even greater cost reductions and further market growth. The Royal Decree 436/2004, which increases support levels and guarantees the support for 20 years, and the Law requiring the integration of solar PV in new buildings are steps in the right direction. As the German 1000 Roof Programme shows, stability and reasonable support levels are crucial to ensure demand for PV modules. Higher support should be considered that cover the difference between deployment costs and the price of the electricity sold to the grid. However, support should be reduced every year as PV costs

decline, which can be accomplished by as decreasing feed-in tariff. There are also social benefits to the elimination of investment subsidies in favour of increases in the feed-in tariff.

A reduction of lead times should also be a priority. This can be assisted by regulations that ensure PV electricity access to the grid. Contrary to the case of wind, the amount of solar PV electricity generated is very small and currently causes no problem to grid stability. The problematic issue of PV investors having to install a transformer should also be dealt with. Their acquisition could be partially subsidised. If the investment subsidies referred to above were earmarked for this, the burden on the public budget would remain constant.

Finally, effective enforcement of the Royal Decree 1663/2000 requiring minimum competencies for PV installers should be enforced. Large-scale awareness-raising campaigns on the benefits of solar PV and on the steps that individuals should take to install this technology should be launched, including demonstration projects in public buildings. Campaigns should be targeted both at the users and at professional groups such as architects and the construction industry [11]. Greater R&D funding and more interaction between industry and R&D centres should be promoted through R + D + D programmes. This co-operation favours the adaptation of research to market needs and, therefore, penetration of the technology.

4.1.2. Wind

The problem of grid connection is the primary barrier to the future diffusion of wind. As with PV, reinforcements of the grid should be partially subsidised and procedures prioritising access to the grid established. Better wind prediction methods and independent studies on the amount of wind energy which can be fed into the grid would be useful. On the other hand, streamlining of procedures to obtain administrative permits could reduce lead times. A catch-all application process that allows all administrative procedures to be reviewed and the issuance of a single permit could improve the process dramatically. Finally, information and awareness-raising campaigns on the benefits of wind electricity would favour public acceptance of wind turbines in the future, when their presence in the landscape is widespread. This would avoid some of the social opposition problems encountered in other countries.

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